PRELIMINARY REPORT ON
THE WATER RESOURCES OF NORTHEAST MAUI

Circular C60

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with
Division of Water and Land Development
DEPARTMENT OF LAND AND NATURAL RESOURCES
State of Hawaii

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By K. J. Takasaki and George Yamanaga

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UNITED STATES GEOLOGICAL SURVEY
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DIVISION OF WATER AND LAND DEVELOPMENT
DEPARTMENT OF LAND AND NATURAL RESOURCES
State of Hawaii

Honolulu, Hawaii
August 1970

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PRELIMINARY REPORT ON THE WATER RESOURCES OF NORTHEAST MAUI, HAWAII

By K. J. Takasaki and George Yamanaga

SUMMARY

Northeast Maui, as described in this report, includes about 165 square miles of the northeast and east slopes of Haleakala. Large forest reserves, on lands too wet for cultivation or at altitudes too high for development, make up much of the area. The lower drier slopes are used mainly for grazing, with smaller areas in orchards and taro cultivation. Population in 1969 was less than 1,500.

Average rainfall is about 180 inches per year, which is equivalent to 1,420 mgd (million gallons per day). Although water use in the area is small, less than 5 mgd, the area is an important watershed and source of water for sugar cane irrigation in central Maui and for domestic use on the upper southwest slopes of Haleakala. An average of about 160 mgd of water is exported for sugar cane irrigation through an extensive system of ditches and tunnels. The principal ditches take all the dry-period water from Makapipi to Honopou Streams at about an altitude ranging from 1,200 to 1,000 feet. About 2 mgd of domestic water is diverted from streams through a collection system running from Waikamoi to Honomanu Stream at an altitude of 4,000 feet and from Waikamoi to Puohokamoa Stream at an altitude of 3,000 feet.

The occurrence of water is largely controlled by the ability of the surface rocks to absorb the abundant rainfall.

Where the surface is comprised of highly permeable lava flows and cinders of the Hana Volcanic Series, the youngest rocks in the area, much of the rain enters the ground as recharge to ground-water bodies and overland stream runoff is low and streams are mostly intermittent. Where the surface is comprised of less permeable and older lava flows of the Kula Volcanic Series, much of the rain is dispersed as overland stream runoff or is quickly returned to the surface from shallow and small ground-water bodies, and streams are mostly perennial.

Most streams are perennial between altitudes 1,000 and 2,000 feet. Streamflow above these altitudes depends mostly on intensity and persistency of rainfall. Development of stream supplies is best in areas where lava flows of the Kula Volcanic Series crop out.

Ground water occurs in perched bodies in Hana and Kula rocks, as artesian perched bodies in the upper transitional part of the Honomanu Volcanic Series, and as basal water in the Hana and Honomanu Volcanic Series near the shore. Other probable occurrences of ground water, not yet identified or tapped by wells and tunnels, include dike-impounded water bodies in Honomanu rocks and inland basal-water bodies in Kula and Honomanu rocks.

The chemical quality of the water is generally excellent in northeast Maui.

Where the surface is composed of highly permeable lava flows and cinders of the Hana Volcanic Series, the frequent rains in the area, much of the rain enters the ground as recharge to ground-water bodies; consequently stream runoff is low and streams are mostly intermittent. Where the surface is composed of less permeable and older lava flows of the Kula Volcanic Series, much of the rain is discharged as overland stream runoff or is quickly returned to the streams from shallow and small ground-water bodies, and streams are perennial.

Most streams are perennial between altitudes 1,000 and 3,000 feet. Extraction above these altitudes depends mainly on the quantity and reliability of rainfall. Development of stream runoff is best in areas where lava flows of the Kula Volcanic Series crop out.

Ground water occurs in perched bodies in upper and lower zones, as dike-confined water in the upper parts of the Honomanu Volcanic Series, and as basal water in the Hana and Honomanu Volcanic Series near the coast. Large probable occurrences of ground water, not yet fully tapped by wells and tunnels, include dike-impounded water bodies in Honomanu rocks and inland basal-water bodies in Kula and Honomanu rocks.

The chemical quality of the water is generally excellent in northeast Maui.

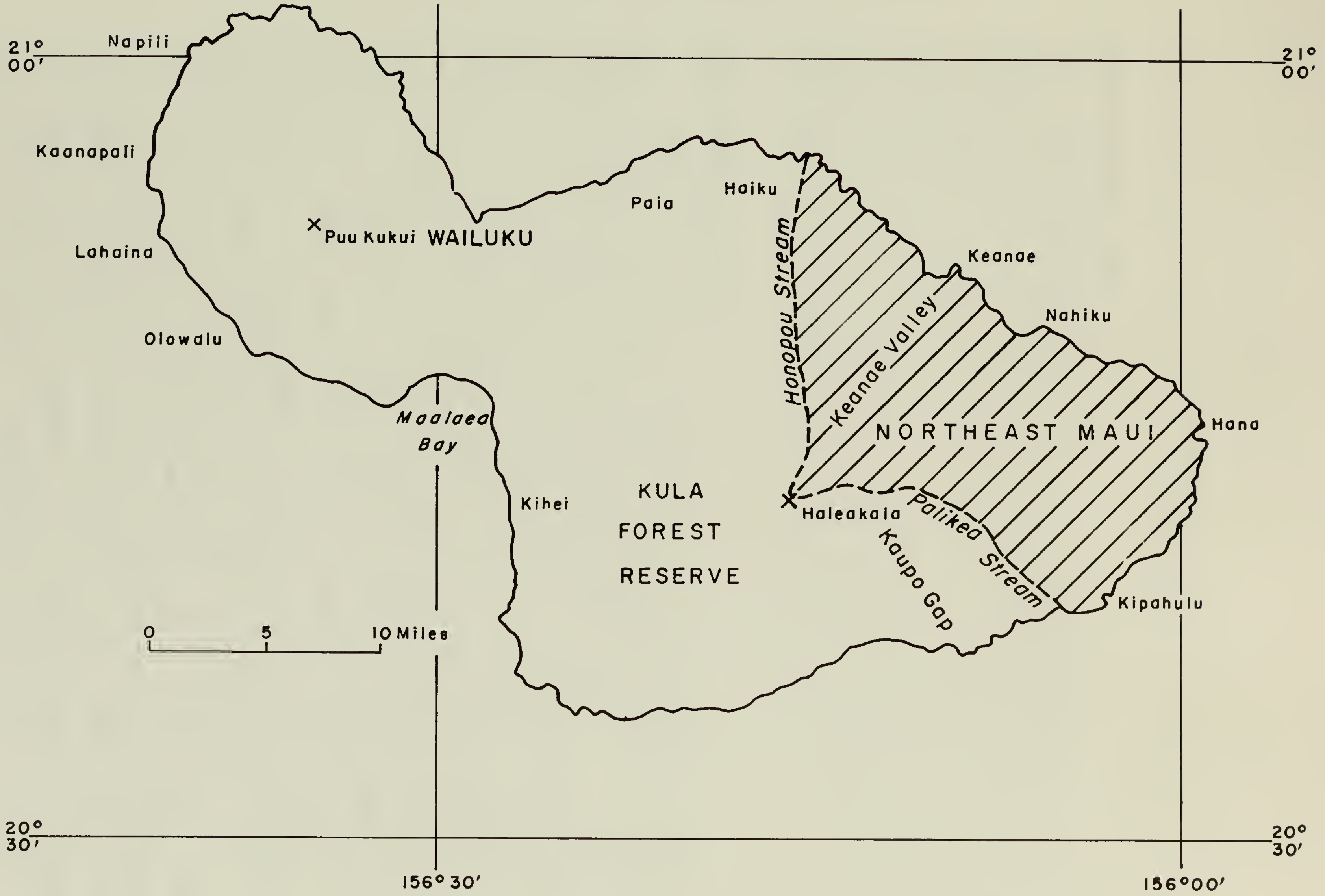

Figure 1. MAP OF THE ISLAND OF MAUI SHOWING AREA OF STUDY

INTRODUCTION

Purpose and Scope

The hydrology and geology of northeast Maui, as outlined herein, is based on published and unpublished reports, on findings of previous investigators, and on records of stream and ditch flows published by the U. S. Geological Survey. It describes, in general, the occurrence of water and some of the geologic features that control its movement and availability. It also summarizes and updates information available on ground water and on stream and ditch flows.

Geographic Setting

Northeast Maui, as described in this report, comprises the northeast and east slopes of Haleakala between Honopou Stream valley and Palikea Stream valley (fig. 1). The area is about 165 square miles and ranges in altitude from sea level to 10,025 feet at the summit of Haleakala. The topography is gently sloping except for the steep sides of gulches and valleys. The gentleness is mainly the result of lava flows, which filled deeply eroded canyons and which later veneered most of the mountain. Stearns and Macdonald (p. 53, 1942) believed that the so-called crater of Haleakala was chiefly, if not entirely, the result of stream erosion, whereby two great amphitheaters at the heads of Kaupo and Keanae Valleys coalesced to form the summit depression.

Large forest reserves make up much of the area. These lands are generally too wet for cultivation or situated at altitudes too high for development. The lower drier slopes are used mainly for grazing, with smaller acres in orchards and taro cultivation. Population in 1969 was less than 1,500.

Previous Investigations

The first systematic studies of the geology and ground-water resources in northeast Maui were made by Powers[1, 2], who prepared two reports. These reports were not published, but some of Powers' findings were included in a report of an island-wide study by Stearns and Macdonald (1942). A comprehensive study of the geology and ground-water resources of the Nahiku area, by G. A. Macdonald, is included in this island-wide study.

Geophysical studies in the Hanawi area near Nahiku were made by Swartz[3], who prepared an open-file memorandum on the results. A further contribution to the petrology of Haleakala was made by Macdonald and Powers (1968).

An intensive test-boring program was begun in the early 1930's by the East Maui Irrigation Co. in the Nahiku area. By 1945, 100 holes were bored and several exploratory tunnels were dug in an area of less than 5 square miles. The exploratory phase of this program ended in 1948 with the drilling of a well at Kuhiwa (well 50), which was 1,411 feet deep and 17-1/2 inches in diameter. The purpose of the program was to locate the source of Big Spring and to determine the geologic control on the occurrence and movement of ground water in the Nahiku area. Swartz made concurrent resistivity

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[1] Powers, H. A., 1934, Geology and ground-water resources of lower Keanae Valley, East Maui. Unpublished manuscript report on file with U. S. Geological Survey, Honolulu, Hawaii.

[2] Powers, H. A., 1934, Geology and ground-water resources of Haleakala section, Maui. Unpublished manuscript report on file with U.S. Geological Survey, Honolulu, Hawaii.

[3] Swartz, J. H., 1941, Memorandum on the results obtained in geophysical investigations in the Hanawi area, island of Maui, by the Section of Geophysics of the U.S. Geological Survey; on file with the U.S. Geological Survey, Honolulu, Hawaii.

studies in the area that complemented the drilling program. The geologic phase of the program was directed by W. O. Clark, geologist, of the Hawaiian Sugar Planters' Association, who, upon his retirement in 1946, was succeeded by D. C. Cox. The test-drilling phase was directed by personnel of the East Maui Irrigation Co.--notably, D. S. Summers and J. H. Foss. The drilling contractor, J. M. Heizer, successfully completed the test borings.

Also in the 1930's, seepage studies of streams from Kailua to Honomanu Streams near the Haiku-uka boundary were made by J. H. Hoffman for the East Maui Irrigation Co. The results of these studies are on file with the East Maui Irrigation Co.

Although none of the results of these investigations were published by the East Maui Irrigation Co., they were made available to the then Division of Hydrography, Territory of Hawaii, who, in cooperation with the Geological Survey, incorporated the results in the island-wide report by Stearns and Macdonald (1942).

Ditches that transport surface water from the wet areas in northeast Maui to the drier ones in central Maui have been built in increments and at different altitudes since 1876. Water records were collected by the Maui Agricultural Co. of the Koolau ditch in 1904, shortly after its completion. The first systematic measurements of the surface-water supply were begun in 1909, and the results were published by the Geological Survey (Martin and Pierce, 1913). Since then, records of flow at gages and at miscellaneous sites have been published by the Geological Survey in Water-Supply Papers.

Acknowledgments

The writers are grateful to the East Maui Irrigation Co. for their permission to use their findings, filed correspondence, and records in this study. Special thanks are given to Doak C. Cox, who made his personal files of the East Maui Irrigation Co.'s activities in northeast Maui readily available.

THE ROCKS AND THEIR WATER-BEARING PROPERTIES

The rocks of the Haleakala volcanic dome emanated from three eruptive zones, the north, east, and southwest rift zones. The area described in this report is between and includes part of the north and east rift zones. Stearns divided the rocks in northeast Maui into three volcanic sequences--the Honomanu, the Kula, and the Hana Volcanic Series (Stearns and Macdonald, 1942). The oldest rocks are basalts of the Honomanu Volcanic Series, which form the bulk of the volcanic dome. The uppermost part of the Honomanu is transitional to the Kula Volcanic Series in containing both picritic basalts and andesitic basalts (Macdonald, 1942, p. 233). Covering this dome are rocks of the Kula Volcanic Series, which include andesites and andesitic and picritic basalts. The eruption of the Kula Volcanic Series was followed by a long period of quiescence, during which time deep canyons were carved into the dome. Then followed a great submergence and subsequent periods of emergences and submergences, which left alluvial fills in valley bottoms. The last sequence of volcanic rocks is called the Hana Volcanic Series. These rocks filled deeply eroded and alluviated canyons and veneered most of the mountain slopes in northeast Maui. The flows of the Hana Volcanic Series are composed of andesitic, picritic, and olivine basalts.

Stratigraphy of northeast Maui (after Stearns and Macdonald, 1942) is summarized in table 1. Distribution of the principal rock units is shown in a generalized geologic map (fig. 2). Results of detailed geologic mapping in Keanae Valley by Powers and in the Nahiku area, especially of stratigraphic units of the Hana Volcanic Series, are included in the study by Stearns and Macdonald (1942).

Table 1. STRATIGRAPHIC SECTION OF NORTHEAST MAUI AND WATER-BEARING PROPERTIES*

Age		Rock assemblage	Thickness (feet)	General character	Water-bearing properties
System	Series				
QUATERNARY	Holocene	Unconsolidated deposits	50±	Chiefly unconsolidated alluvium. Includes talus fans in depressions and calcareous sand along beaches.	Permeable to high permeable but dry except near shore, where water in them is brackish.
				Local erosional unconformity	
	Pleistocene and Holocene	Hana Volcanic Series		Chiefly lava flows. Includes cones, dikes, and fire-fountain deposits.	
			10 to 1,000	Lava flows: Consist of olivine and picritic basalt, basaltic andesite, and andesite. Where flows filled canyons they are 1,000 feet thick or more; elsewhere they are 100-200 feet thick.	Lava flow: Most highly permeable excepting for dense massive parts that filled canyons.
			20 to 600	Cones: Consist of bedded cinders, spatter, and layers of very thin scoriaceous lava along fissures.	Cones: Highly permeable, carry very small perched water bodies on intercalated soil layers in wet areas.
			1 to 10	Dikes:	Dikes: Poorly permeable; confine water in rift zones.
			1 to 20	Fire-fountain deposits: Consist of friable vitric ash and pumice deposits blown from cones by the wind.	Fire-fountain deposits: Permeable but contain no water.
				Erosional unconformity	
	Pleistocene(?)		750±	Kipahulu Formation: Composed of basalt, picritic basalt, and basaltic andesite in Kipahulu Valley only.	Permeable and probably carries large quantities of water at its base.
				Erosional unconformity	
		Consolidated sedimentary deposits	150±	Consolidated sedimentary deposits consisting of older alluvium, ancient talus, landslide deposits, and marine noncalcareous material. In part contemporaneous with Hana Volcanic Series.	Mostly poorly permeable and acts as perching member for overlying permeable rocks.
				Great erosional unconformity	
TERTIARY(?)		Kula Volcanic Series		Chiefly lava flows: Includes cones, tuffs, and dikes.	
			50 to 2,000	Lava flows: Consist of mostly massive basaltic andesite, andesite, basalt, and picritic basalt.	Lava flows: Fairly permeable and carry perched water in rainy areas, especially at the base of valley fills of lava.
			20 to 600	Cones: Friable to firmly compacted bedded cinders, spatter, and thin layers of scoriaceous lava along fissure zones.	Cones: Fairly permeable and perch a few small springs and seeps.
			1 to 40	Tuff: Friable weathered vitric tuff commonly interbedded with lava flows.	Tuff: Poorly permeable and acts as perching member.
			1/2 to 10	Dikes:	Dikes: Poorly permeable and confine water in rift zones.
				Transitional in most places	
		Honomanu Volcanic Series	8,500±	Chiefly lava flows; dikes exposed only in Kipahulu Valley. Lava flows of mostly thin-bedded, highly vesicular primitive olivine basalt except in upper transitional zones, where massive flows occur.	Lava flows generally highly permeable except in upper transitional lavas, where water is perched under artesian conditions in Nahiku area. Dikes confine water in rift zones.

*Stratigraphic names and age assignments in the Keanae and Nahiku areas after Stearns and Macdonald (1942, p. 95 and 230) and Macdonald and Davis (in Avias, Jacques, 1956).

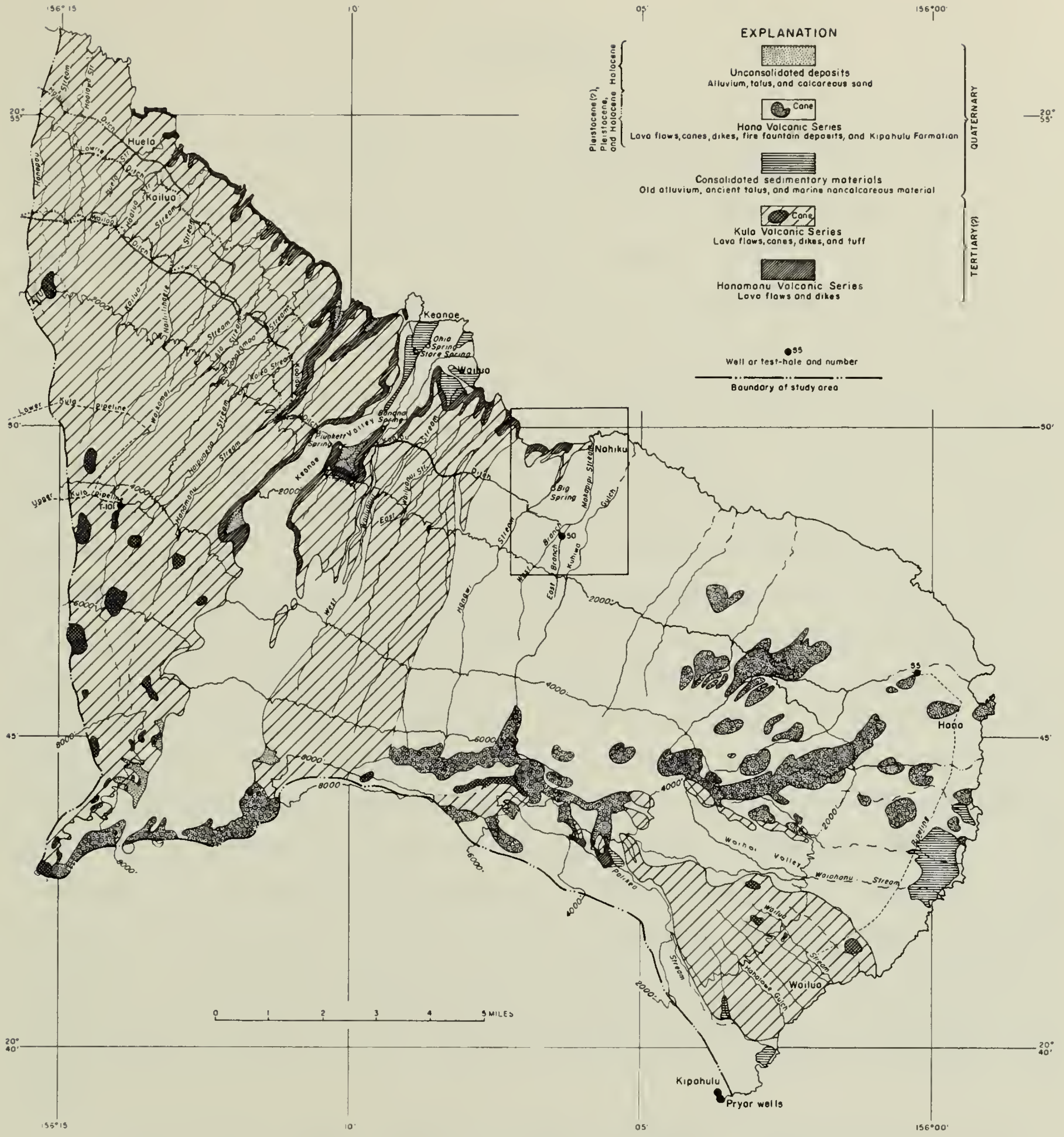

Figure 2. GENERALIZED GEOLOGIC MAP OF NORTHEAST MAUI SHOWING SELECTED WELLS AND SPRINGS

RAINFALL

Rainfall is highest on the windward side of northeast Maui between altitudes of 2,000 and 4,000 feet (fig. 3). Rainfall decreases rapidly above and below this belt and less rapidly away from the ends of it. Mean annual rainfall ranges from about 30 inches near the summit of Haleakala to about 400 inches in the zone of high rainfall on the windward side.

Rainfall maps showing lines of equal rainfall in Maui were published by the Territorial Planning Board (1939), Stearns and Macdonald (1942), and Taliaferro (1959). Unpublished maps include one prepared by Leopold4/, and one by the U. S. Weather Bureau in 1955. All the maps show lines of equal mean annual rainfall except that prepared by Taliaferro, which shows lines of equal median annual rainfall. The map prepared by Leopold represents a detailed study of rainfall in the water-catchment area of the East Maui Irrigation Co.'s irrigation system. The company pays for irrigation water derived from land not under their jurisdiction and the payments are based on this rainfall map. This map was not used in this report because it does not include all of the study area. The rainfall map, shown in figure 3, was taken from the U. S. Weather Bureau map prepared in 1955. Average rainfall in northeast Maui estimated from figure 3 is about 180 inches per year, which is equivalent to 515 billion gallons per year or 1,420 mgd (million gallons per day).

All of the maps show the same general distribution of rainfall in northeast Maui but differ somewhat in detail. For

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[4] Leopold, L. B., 1949, The annual rainfall of East Maui: An unpublished report to the U. S. Geological Survey and East Maui Irrigation Co. on file with Pineapple Research Institute and Hawaiian Sugar Planters' Association, Honolulu, Hawaii.

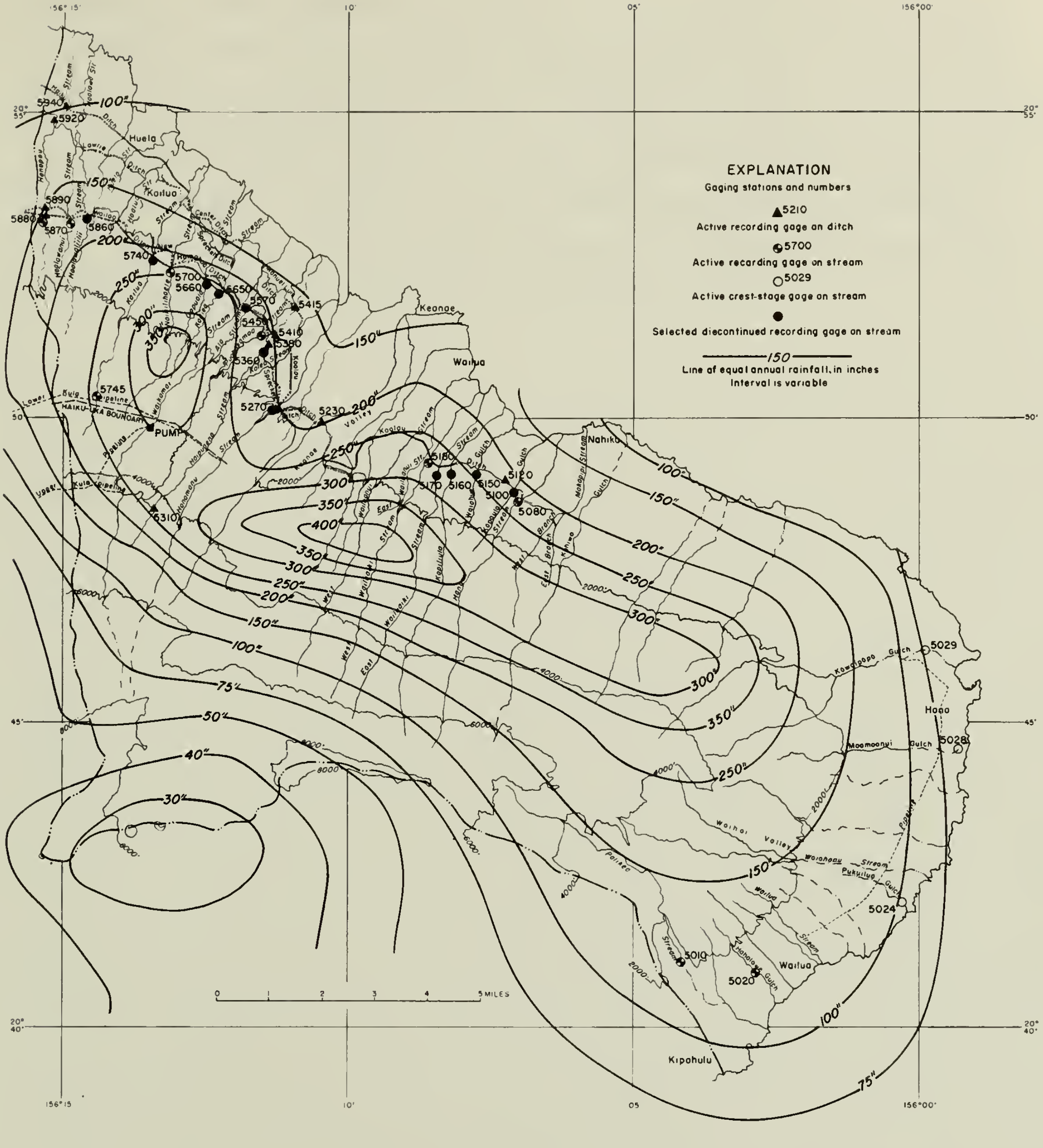

Figure 3. MAP OF NORTHEAST MAUI SHOWING DISTRIBUTION OF MEAN ANNUAL RAINFALL AND LOCATION OF SELECTED RAINFALL AND STREAMFLOW STATIONS, DITCHES, AND PIPELINES

instance, maps prepared by Stearns and Macdonald and by Taliaferro show two separated annual rainfall maxima, while the other two show only one. On the other hand, the map prepared by Leopold shows an annual rainfall maximum of 400 inches, as compared to 280 inches for that prepared by the Territorial Planning Board. Except for the separated maxima in Leopold's map, there is no significant difference between this map and the one prepared by the U.S. Geological Survey.

WATER RESOURCES

General Statement

The amount and distribution of rainfall in northeast Maui have received considerable study by many and are probably best known of the elements in the hydrologic cycle; the rates of evaporation and transpiration are least known. Streamflow at and along the Koolau-Wailoa ditch level from Makapipi to Honopou Streams at about an altitude of 1,200 feet is adequately known, but elsewhere, streamflow data are sparse. The occurrence of ground water has been extensively explored by numerous test holes in the Nahiku area. Elsewhere, there is little or no ground-water information and only general descriptions of its occurrence are available.

The occurrence of water is largely controlled by the ability of the surface rocks to absorb the abundant rainfall. Where the rocks are poorly to only fairly permeable, as are the lava flows of the Kula Volcanic Series in about half the area, much of the rain is dispersed as overland stream runoff or is quickly returned to the surface as springflow and streams are mostly perennial. Where the surface rocks are highly permeable, as are the lava flows and cinders of the Hana Volcanic Series, much of the rain enters the ground as recharge to ground-water bodies, and overland stream runoff is low and streams are mostly intermittent. Some of these intermittent streams become perennial at low altitudes near the coast, where they are fed by discharging ground water.

In general, development of stream supplies would be preferable over that of ground-water supplies in areas where lava flows of the Kula Volcanic Series crop out and vice-versa in areas where lava flows and cinders of the Hana Volcanic Series crop out.

Streams

Most streams are perennial between an altitude of 1,000 and 2,000 feet. Streamflow above this altitude range depends mostly on intensity and persistency of rainfall. Rainfall is plentiful on the northeast slopes of Haleakala--as much as 400 inches per year in the rainy belt between altitudes of 2,000 and 4,000 feet (see fig. 3). But rainfall decreases sharply above an altitude of 4,000 feet, and streams that extend much higher than this altitude have only small flows. Below an altitude of 1,000 feet, many perennial streams go dry either because their dry-weather flow is diverted or because they lose water to highly permeable rocks of the Hana Volcanic Series. Some other streams gain significantly because their channels intersect large ground-water bodies.

The streams in the northwestern part--from the Makapipi to the Honopou--are the source of water used to irrigate sugar cane on the dry western slopes of Haleakala. An average of about 160 mgd is exported for irrigation from this "ditch" country through an extensive system of ditches and tunnels. The principal ditch of the system--the Koolau-Wailoa ditch--takes all dry-period water from the streams at altitudes ranging from 1,000 to 1,200 feet. Other ditches are located at lower altitudes and capture waters which flow downstream past the Koolau ditch intakes or arise from ground-water sources below the ditch level.

In addition to the irrigation water system, a domestic water system belonging to the Maui Board of Water Supply takes water from flowing streams between Waikamoi and Honomanu. The Upper Kula Pipeline taps the streams at an altitude of 4,000 feet and delivers water to the western and southern slopes of Haleakala. A Lower Kula Pipeline system is now being completed and will divert water from the streams at an altitude of 3,000 feet.

These extensive systems of ditches divert all the low and medium flows from the streams lying west of Honomanu Stream so that water flows to the ocean only when rains are heavy. East of Honomanu Stream, however, the only large diversion is by Koolau ditch, which extends to Makapipi Stream along the 1,200-foot level. Water that arises in streams below the ditch level, estimated by Cox[5] from budget studies to total about 35 mgd, mostly flows unused into the ocean.

Beyond Makapipi Stream and extending to Waihoi, streams are ephemeral in spite of the high rainfall. The ground surface in the section is highly permeable, fresh Hana rocks that permit all but the heaviest rains to sink rapidly into the ground. The ground water does not reappear on the surface, apparently escaping to sea, at or below sea level. Runoff from excessive rains, at times, have resulted in damaging flood flows in the normally dry streams.

Streams are perennial south of Waihoi Valley, between the Wailua Stream and the boundary of the study area. Water diverted from Wailua Stream is taken by pipeline to supply water for domestic and stock uses in the area extending to Hana. Remains of ditches constructed to supply water for fluming of sugar cane stalks can still be found south of Wailua in what were former cane fields of the old Kipahulu Sugar Co.

Streamflow Records. Although records of ditchflow began in the late 1870's, systematic measurement of the flow of streams began in 1910, with the installation of staff gages on several streams above points of diversion. These stations

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[5] Cox, J. B., 1954, Rainfall and ditch-flow study of east Maui watershed. Unpublished correspondence report to East Maui Irrigation Co. dated December 28, 1954.

and others installed in the area during a long period thereafter were necessarily located at or near ditch level because the ditch trail was the only thoroughfare through this rough, thickly forested area. In subsequent years, all the principal streams in this section have been gaged at the ditch level at one time or another. The locations of selected streamflow stations, ditches, and pipelines are shown in figure 3.

Beginning in 1919, gages were installed on streams between and including Honomanu and Kailua Streams, at about an altitude of 3,000 feet, along the Haiku-uka boundary line. The purpose of these gagings was to obtain data so that determination could be made of the proportion of water falling on private and State watershed lands above the ditch.

Gaging of Palikea (5010) and Hahalawe (5020) Streams began in 1927. These two are the only fully gaged streams which are not intercepted by the ditch system.

From 1932 to 1947, several streams in the Nahiku area were gaged at altitudes of 500 and 600 feet to determine the amount of water that might be diverted by extending one of the lower ditches.

Since 1963, crest-stage stations (5024, 5028, and 5029) have been installed on ephemeral streams near Hana to obtain data on the magnitude and frequency of floods in the area. Annual peak discharges for these crest-stage stations and selected regular stations are published in the series of progress reports, the latest of which is number 11 (Lee, R., and Fowler, K., 1969).

Streamflow Characteristics. Flow-duration curves were drawn for several selected streams--some of which are shown in figures 4 and 5. Table 2 summarizes information derived from the flow-duration curves. In this table, the average discharge and the percentage of time it was equaled or exceeded are given in columns 4 and 5. Given in columns 6 to 12 are

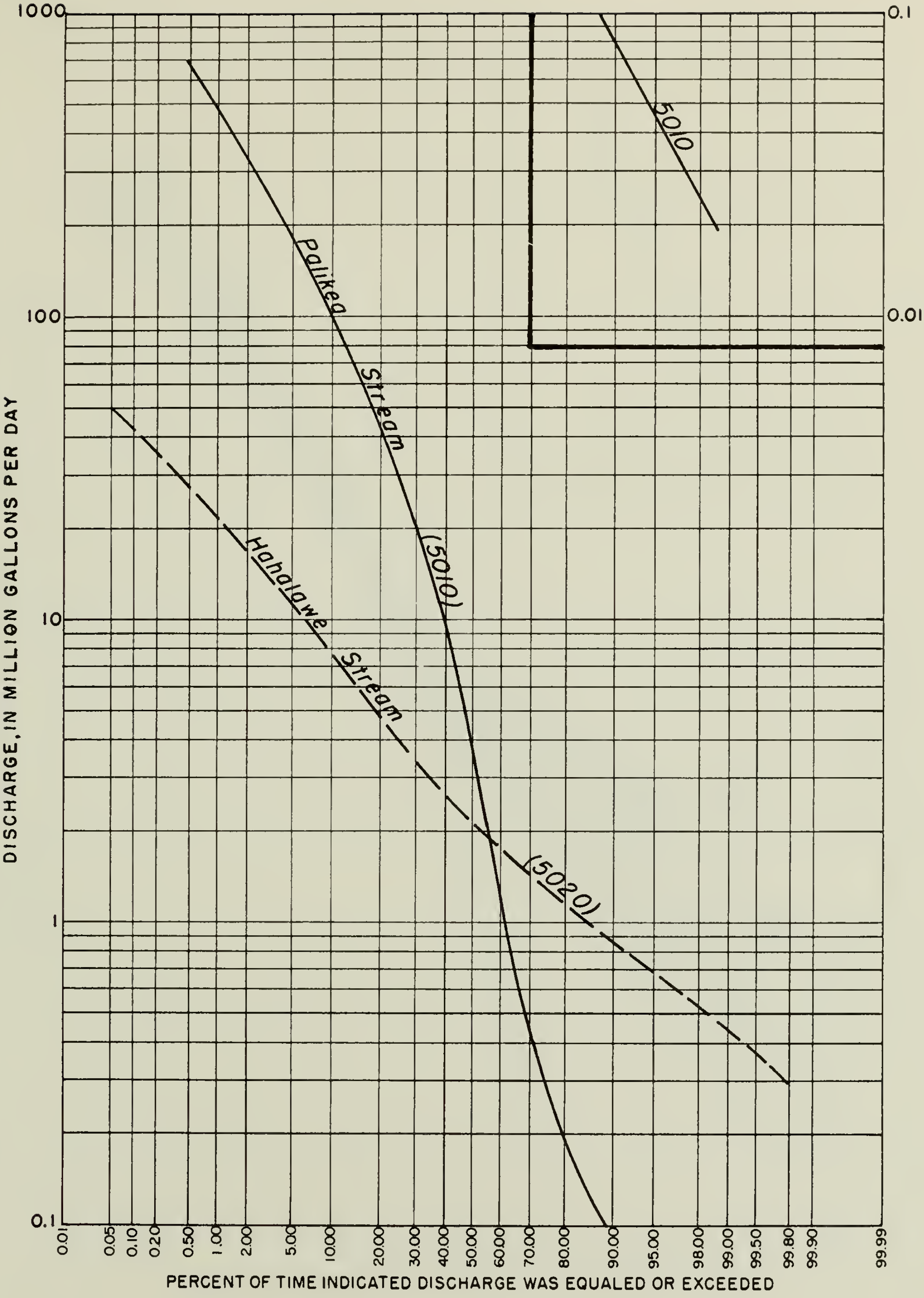


Figure 4. FLOW-DURATION CURVES OF DAILY FLOWS FOR PALIKEA AND HAHALAWE STREAMS

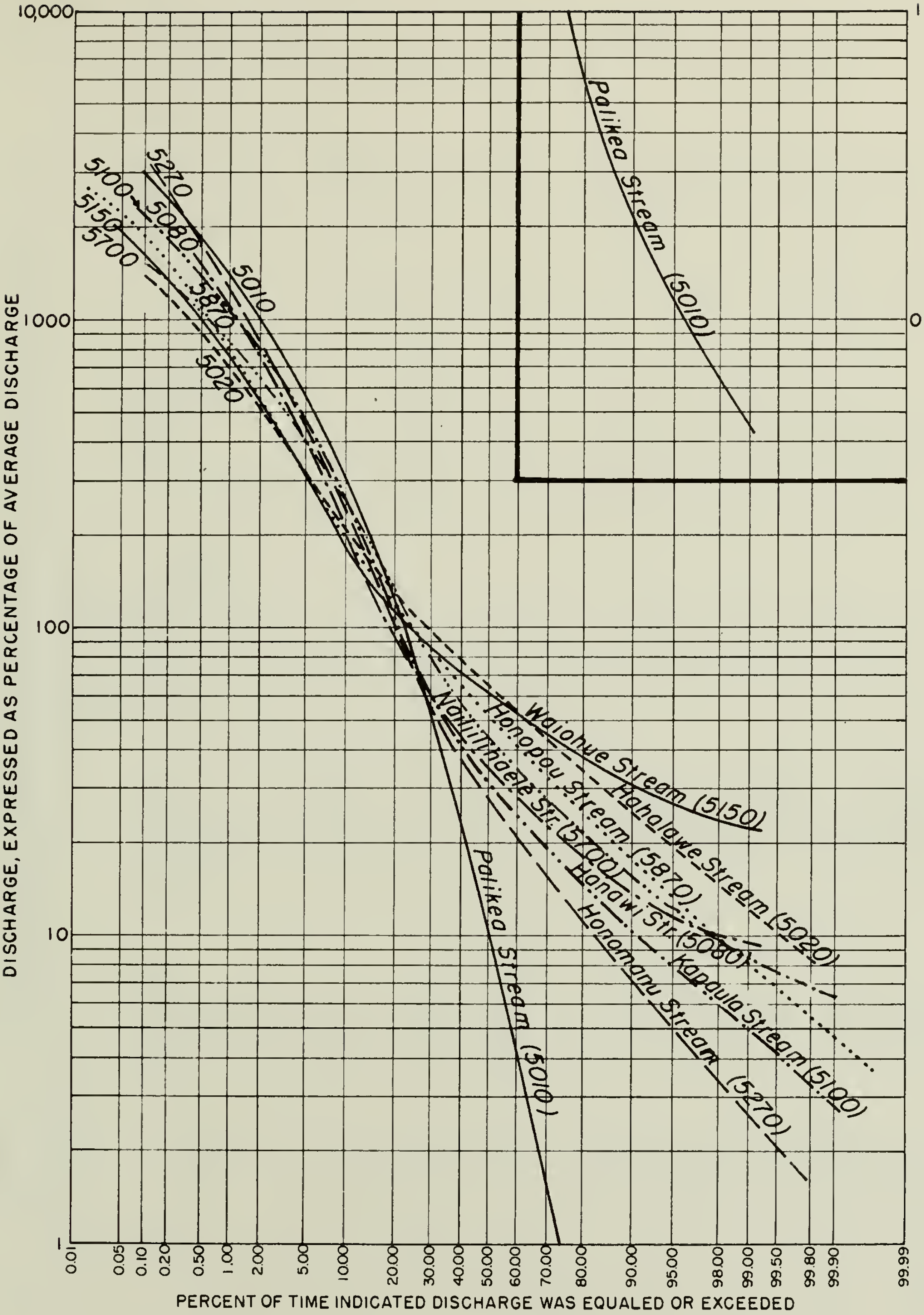


Figure 5. FLOW-DURATION CURVES OF DAILY FLOWS FOR SELECTED STREAMS IN NORTHEAST MAUI

Table 2. INFORMATION DERIVED FROM FLOW-DURATION CURVES OF SELECTED STREAMFLOW STATIONS IN NORTHEAST MAUI

Stream (1)	Station No. (2)	Drainage area sq mi (3)	Average discharge mgd (4)	Percentage of time average discharge was equaled or exceeded (5)	Discharge (in percentage of average) equaled or exceeded for percentage of time indicated by column headings						
					1 (6)	10 (7)	20 (8)	50 (9)	70 (10)	90 (11)	99 (12)
Palikea	5010	6.29	36.3	22	1,320	275	55	11	1.5	0.2	0.04
Hahalawe	5020	0.43	3.52	28	653	213	94	60	40	24	13
Hanawi	5080	3.49	14.7	19	1,090	211	58	35	23	14	9.5
Kapaula	5100	0.69	10.8	21	1,037	250	63	32	18	11	4.9
Waiohue	5150	0.54	7.55	25	741	192	85	58	44	30	24
Kopiliula	5160	4.31	17.7	20	1,186	197	62	34	20	12	6.3
East Branch Wailuaiki	5170	3.11	19.7	19	1,065	218	61	34	22	13	7.4
Honomanu	5270	3.17	15.3	21	1,240	235	60	28	16	7.8	2.7
Haipuaena	5360	1.1	9.92	23	1,010	242	70	36	19	6.0	1.6
Alo	5570	0.47	4.78	26	941	240	84	44	25	14	7.5
Kaaiea	5650	0.58	4.43	25	857	248	84	44	26	14	8.1
Oopuola	5660	0.2	1.75	26	891	234	86	43	25	13	7.7
Nailiilihaele	5700	3.58	21.9	25	783	237	80	46	30	17	8.6
Kailua	5740	1.01	18.9	22	1,058	238	63	33	20	11	5.3
Hoolawaliilii	5860	0.55	4.87	25	780	177	86	60	44	30	15.4
Honopou	5870	0.64	3.18	27	786	208	88	53	33	18	8.5

discharges (expressed as percentages of average discharge), which were equaled or exceeded for various percentages of time as indicated by the column headings.

For example, at Palikea Stream (5010), where the average discharge of 36.3 mgd was equaled or exceeded 22 percent of the time, the flow equaled or exceeded 90 percent of the time (Q_{90}) was 0.2 percent of 36.3 mgd or 0.07 mgd; median flow, Q_{50}, was 11 percent of 36.3 mgd or 4.0 mgd.

Although adjacent streams generally have similar characteristics, there are exceptions. Palikea (5010) and Hahalawe (5020) Streams are nearly adjacent; however, their flow characteristics are decidedly different, principally because these streams flow across ground surfaces that are geologically very different--very porous lavas in Palikea, not quite so porous in Hahalawe.

Hahalawe, Waiohue (5150), and Hoolawaliilii (5860) Streams, although far apart, have similar flow characteristics in that their low flows are much better sustained than the other streams (compare values shown in columns 10 to 12).

The small values in columns 10 to 12 for Honomanu and Haipuaena Streams do not necessarily indicate poorly sustained low flows in these streams because some flow is diverted into the Kula pipeline system upstream of the gaging stations.

Development

Early Development. Development of the water resources probably began with the diversion of streamflow for the irrigation of taro, presumably soon after the early Hawaiians first settled in the area. Taro is still being grown in parts of the area.

East Maui Irrigation Systems. Extensive development, however, did not start until the late 1870's. Under a lease obtained from the government in September 1876, a group incorporated as the Hamakua Ditch Co. in 1878 and consisting of the

Haiku Sugar Co. (one of several operating then on the northeastern end of central Maui), the firm of Alexander and Baldwin, and James M. Alexander, and Thomas H. Hobron, was authorized "...to take, draw off, conduct away and use the water in and from certain streams and sources of water in..." The streams included Nailiilihaele, Kailua, Hoalua, Huelo, Holawa, and Honopou Streams. The aqueduct constructed under this lease was the Old Hamakua ditch, which has been abandoned since the New Hamakua ditch was constructed.

In July 1878, Claus Spreckels was granted a lease "...to take, draw off and conduct away and use..." certain waters in the Hamakua and Koolau districts, subject to not interfering with prior or vested rights of other parties. Streams included in this lease were those between and including the Halehaku (about 1 mile west of Honopou Stream outside project boundary) and Waikamoi. Spreckels and Haiku ditches were constructed under this lease prior to 1885, and took the waters of these streams to the lands of Hawaiian Commercial and Sugar Co. (HC&S) under Spreckels' control. Center ditch, running from Waikamoi to Nailiilihaele Streams was completed in 1893. Manuel Luis ditch running from Kolea Stream to Waikamoi was completed in 1900. Lowrie ditch, which begins at Nailiilihaele Stream, was essentially completed between 1899 and 1901.

Early in 1902, water licenses were granted for developing the waters between Honomanu and Nahiku, and the present Koolau ditch was constructed during 1904 and 1905. Costs were shared on a one to two basis between Hawaiian Commercial and Sugar Co. and Hamakua Ditch Co., and the water derived was proportionately divided at the lower end of Koolau ditch, at Alo Stream.

In 1904, Maui Agricultural Co. was formed as a result of a merger between Haiku Sugar Co. and another, the Paia Plantation and so with Hawaiian Commercial and Sugar Co., there were only two plantations on the west slopes of Haleakala.

In 1912, the two companies pooled their water-system operations and formed the East Maui Irrigation Co., which has since improved and maintained the various ditches. Development of high-level ground water by tunneling above ditch level has increased flows somewhat in the Nahiku area.

Kula Water System. A system for developing water for domestic, stock and truck crop irrigation use on the west slopes of Haleakala was begun in 1912. A dam and intake was constructed in Waikamoi Stream, at an altitude of about 4,500 feet and a long pipeline (the Upper Kula Pipeline) took water to the Kula area. The supply of water initially developed soon became inadequate during times of drought as the demand increased. Storage facilities were added and the intake area eventually extended to Honomanu Stream but it became evident that the amount of water available at an altitude of 4,000 feet would not be enough to meet the demand.

Streamflow at an altitude of 3,000 feet, considerably larger than at the higher altitude, was then utilized with a collection system running from Puohokamoa Stream to Waikamoi Stream. A high-lift pump was installed in a collection pool on Waikamoi Stream and about 1 mgd additional water was delivered to the pipeline at an altitude of 4,000 feet. Latest improvements of the system include two 15 million-gallon reservoirs constructed just off Waikamoi at an altitude of 4,000 feet and the construction of a new system at an altitude of 3,000 feet (Lower Kula Pipeline), which begins at Honomanu Stream and ends in the Kula area. This system is designed to deliver an additional 3 mgd.

Ground Water

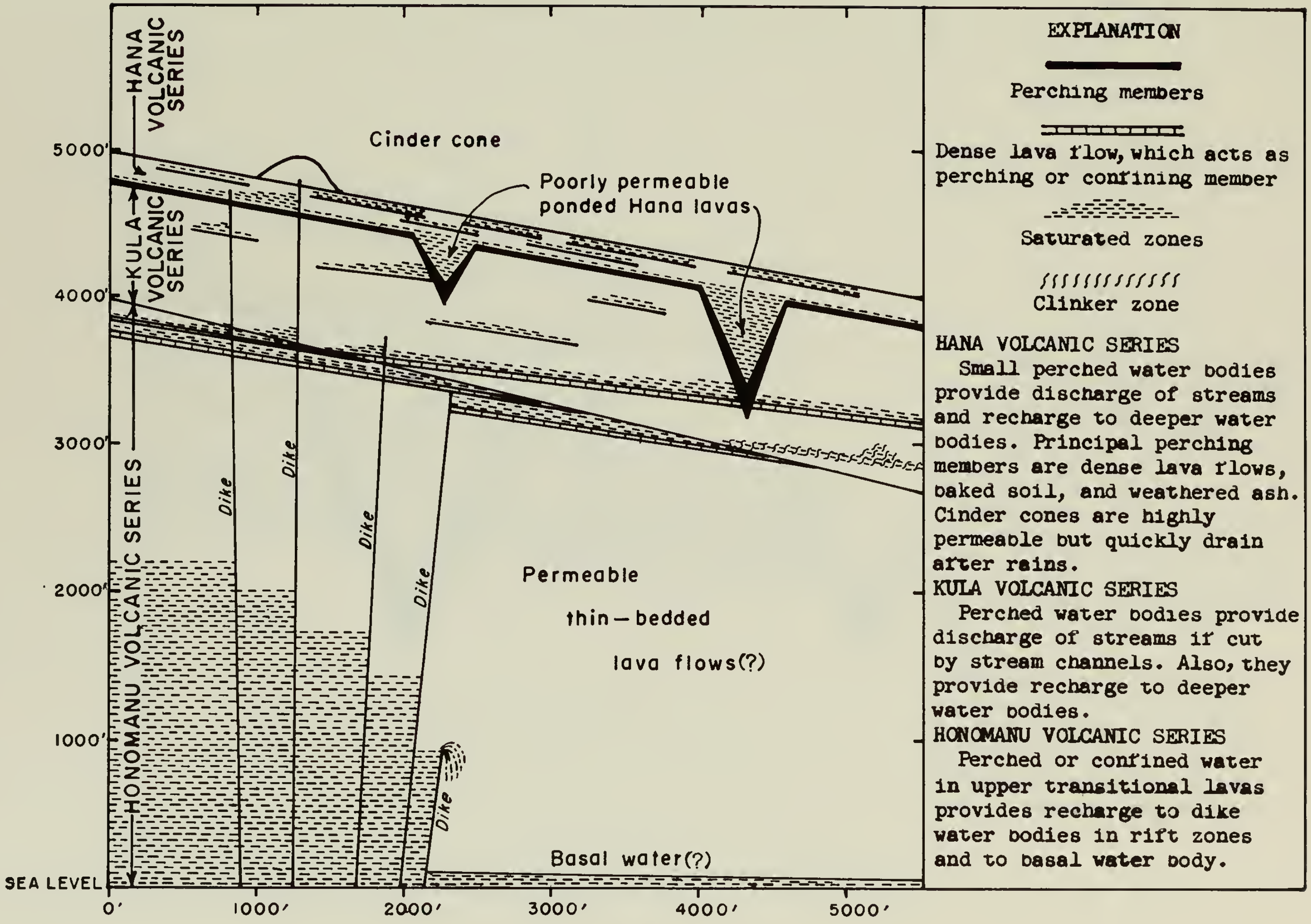
A significant, but yet undetermined, part of the average 1,420 mgd of rain that falls enters the ground and becomes ground water. A large part of the rain is quickly absorbed when it falls on fresh permeable lava flows and cinders of the

Hana Volcanic Series. In contrast, only a small part of the rain falling on poorly permeable lava flows of the Kula Volcanic Series is absorbed. In most places, infiltration is not deep but is limited to or is temporarily detained in small and shallow water bodies. These bodies, mostly perched, provide the base flow of springs and streams where they intersect the land surface. If they do not discharge at the surface, they provide recharge to deeper water bodies by leakage or spillage from storage. Where the Kula crops out, the small recharge limits storage and discharge of perched water even though the formation includes many perching members.

Deeper water bodies are likely to include dike-confined water in the rift zones, perched water in the upper transitional Honomanu rocks, and basal water. So far, artesian perched water in the Honomanu rocks has been tapped by well 50 and basal water in Hana rocks by well 55. Well 50 is unused, and well 55 is pumped at about 100,000 gpd (gallons per day). Test hole 101 drilled from an altitude of 4,300 feet in the northwest rift zone near Waikamoi Gulch failed to reach dike-confined water or perched water at a depth of 650 feet in Kula rocks. Water is probably confined by dikes deeper in the rift zones but this is not indicated at the surface, and no wells have been drilled to confined-water zones. It is also likely that basal-water bodies exist where Kula and Honomanu rocks extend below sea level. Springs on and near the coast discharge from these water bodies.

Diagrammatic sketches showing the various types of perching and confining members and associated water bodies are shown in figures 6, 7, and 8.

The discharge of perched springs and tunnels have been estimated at about 25 and 6 mgd, respectively, in northeast Maui (Stearns and Macdonald, 1942, p. 203). Pumpage of about 100,000 gpd from well 55 in the Hana area represents the only ground water pumped. There is little or no information on

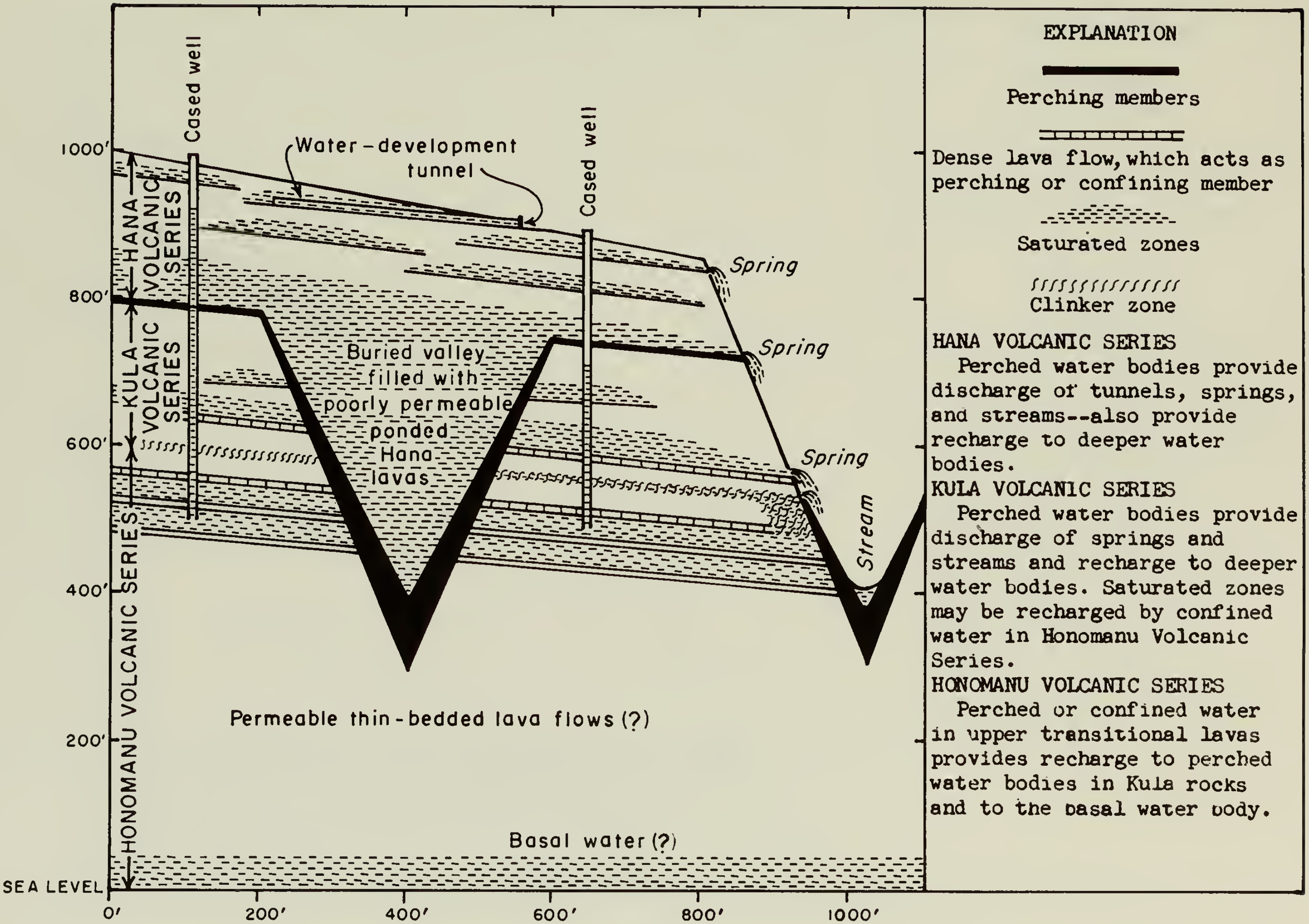


HANA VOLCANIC SERIES
Small perched water bodies provide discharge of streams and recharge to deeper water bodies. Principal perching members are dense lava flows, baked soil, and weathered ash. Cinder cones are highly permeable but quickly drain after rains.

KULA VOLCANIC SERIES
Perched water bodies provide discharge of streams if cut by stream channels. Also, they provide recharge to deeper water bodies.

HONOMANU VOLCANIC SERIES
Perched or confined water in upper transitional lavas provides recharge to dike water bodies in rift zones and to basal water body.

Figure 6. DIAGRAMMATIC SKETCHES SHOWING VARIOUS PERCHING AND CONFINING MEMBERS AND ASSOCIATED WATER BODIES AT DIFFERENT ALTITUDES



EXPLANATION

Perching members

Dense lava flow, which acts as perching or confining member

Saturated zones

Clinker zone

HANA VOLCANIC SERIES
Perched water bodies provide discharge of tunnels, springs, and streams--also provide recharge to deeper water bodies.

KULA VOLCANIC SERIES
Perched water bodies provide discharge of springs and streams and recharge to deeper water bodies. Saturated zones may be recharged by confined water in Honomanu Volcanic Series.

HONOMANU VOLCANIC SERIES
Perched or confined water in upper transitional lavas provides recharge to perched water bodies in Kula rocks and to the basal water body.

Figure 7. DIAGRAMMATIC SKETCHES SHOWING VARIOUS PERCHING AND CONFINING MEMBERS AND ASSOCIATED WATER BODIES AT DIFFERENT ALTITUDES

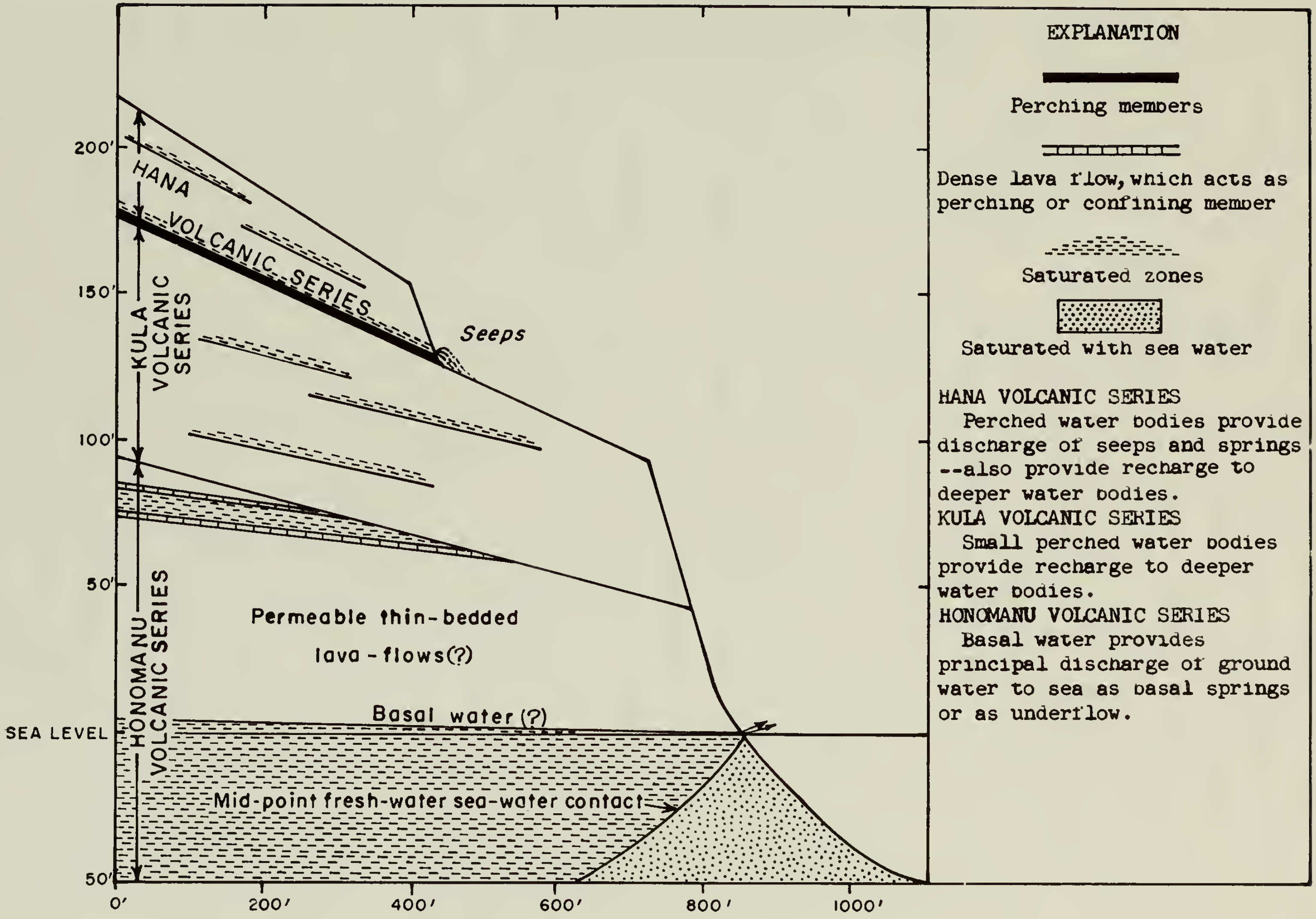

EXPLANATION
Perching members
Dense lava flow, which acts as perching or confining member
Saturated zones
Saturated with sea water
HANA VOLCANIC SERIES
Perched water bodies provide discharge of seeps and springs --also provide recharge to deeper water bodies.
KULA VOLCANIC SERIES
Small perched water bodies provide recharge to deeper water bodies.
HONOMANU VOLCANIC SERIES
Basal water provides principal discharge of ground water to sea as basal springs or as underflow.
HANA
VOLCANIC SERIES
KULA VOLCANIC SERIES
HONOMANU VOLCANIC SERIES
Seeps
Permeable thin-bedded lava-flows(?)
Basal water (?)
Mid-point fresh-water sea-water contact
200'
150'
100'
50'
SEA LEVEL
50'
0'
200'
400'
600'
800'
1000'

Figure 8. DIAGRAMMATIC SKETCHES SHOWING VARIOUS PERCHING AND CONFINING MEMBERS AND ASSOCIATED WATER BODIES AT DIFFERENT ALTITUDES

streamflow at low altitudes near the shore, which is needed to evaluate the ground-water component of this flow discharging to sea. Because the measured or known discharge is extremely small, this information must be known if the total discharge and dispersal of ground water at the shore are to be evaluated. The perched springs and tunnels and their discharges are shown in tables 3 and 4, respectively.

Nahiku Area. The report by Macdonald (1942, p. 227-274) on the geology and ground-water resources of the Nahiku area summarizes the findings of investigators to about the end of 1941. Quoting the abstract from this report, "In the Nahiku area basal water occurs largely in the Honomanu basalts. Perched water occurs in many of the latter lavas, generally following the axes of buried valleys. The members which perch the water are mostly ashy soil beds, although an unusually extensive, thick layer of much decomposed clinker also appears to be a supporting member. Most of the water travels through the basal clinker members of aa lavas. Artesian water is encountered in the upper, transitional part of the Honomanu Volcanic Series. The aquifer is permeable porphyritic pahoehoe; the confining members are relatively impermeable non-porphyritic aa." According to the report, this artesian aquifer supplies Big Spring in Hanawi Gulch.

From 1942 to 1945, an additional 13 test holes were drilled by the East Maui Irrigation Co. By 1947, interest in the Nahiku area was confined to three perched-water bodies, the normal non-artesian water body on top of the Big Falls flow of the Hana Volcanic Series in the Kuhiwa area, and the 800- and 1,100-foot bodies of perched artesian water in Honomanu rocks in the Hanawi and Makapipi-Kuhiwa areas, respectively. The artesian aquifer was described by Doak C. Cox in a report of the Hawaiian Sugar Planters' Association Geology Department for the year ending September 1946. Quoting from this report, "The aquifer which is 50 to 200 feet thick is a

Table 3. PERCHED SPRINGS, NORTHEAST MAUI*

No.	Name	Altitude	Average daily discharge, mgd	Average temperature °C
18	Ohia	230	3.04	
19	Store	245	2.20	
20	Banana	750	2.88	
21	Plunkett	1,000	1.75	
22	Ogino	1,237	.20	16.9
23	Pali	950	.50	
24	Silveno	1,171	.18	16.5
25	Kapaula	1,113	.44	17.4
26	Big	546	10.40	14.9
27	Hanawi 1	767	1.17	17.6
28	Hanawi 2	660	.88	18.1
29	West Makapipi	1,185	.49	15.8
30	Ulaino	200	.10	
31	Clark	2,900	.10	
32	Waihoi	2,300	.08	
33	Lower Hahalawe	2,280	.08	
34	Upper Hahalawe	2,760	.03	
35	East Puaaluu	1,100	.10	
36	West Puaaluu	1,120	.08	
		Total	25 (rounded)	

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*After Stearns and Macdonald, 1942. Number and location of springs are shown on plate 1 of this report.

Table 4. WATER-DEVELOPMENT TUNNELS, NORTHEAST MAUI*

No.	Valley or name	Yield, mgd	Average temperatures °C
32	Waikamoi	0.01	
33	Keanae	.05	
35	Paakea No. 3	.17	17.3
36	Paakea No. 1	.31	17.2
38	Paakea No. 4	.01	
39	Waiaaka	.85	17.3
40	Kapaula No. 3	.45	17.4
41	Kapaula No. 4	.01	17.5
42	Kapaula No. 2	.25	17.4
43	Kapaula No. 1	.15	17.4
44	Hanawi No. 1	.05	
45	Hanawi No. 2	.10	18.1
46	Hanawi No. 3	1.00	16.8
51	West Makapipi No. 2	.05	17.7
52	West Makapipi No. 1	.02	
53	West Makapipi No. 3	.10	15.8
54	East Makapipi No. 2	.02	
55	East Makapipi No. 1	2.00	17.3
56	Pogue	.30	
	Total	6 (rounded)	

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*After Stearns and Macdonald, 1942. Number and location of tunnels are shown on plate 1 of this report.

series of pervious pahoehoe and clinkery aa flows interbedded with dense aa flows. The upper and lower confining members are dense, massive, and continuous aa flows. The stratigraphy of the flows may be fairly certainly worked out using correlations between drilled holes based on petrographic differences between flows. The west boundary of the low pressure body (800-foot body), the north (makai) boundary of the bodies, and the boundary between the two bodies are known within limits. In general the limits are wide, but the north boundary in one place is known to be only a few hundred feet apart. It is not a change in the flows, but must be a steep dam across the flows, such as a dike or fault. The boundary between the bodies is likewise probably a dike or fault, because the bodies occupy the same aquifer. The known area of the bodies is about 300 acres or 1/2 square mile, but the high pressure area (1,100-foot body) probably extends much farther mauka (toward the mountains) and may extend much farther eastward than it is now known." W. O. Clark, in a letter dated February 11, 1944 to J. H. Foss, manager of the East Maui Irrigation Co., also believed that the sharp boundary between the artesian areas and between the artesian and non-artesian areas was probably caused by dike intrusions.

The artesian areas, as delineated by Cox[6/], are shown in figure 9. The triangular area defined by well 50 and test holes 99 and 99-1 is the 1,100-foot artesian body, and the other defined by test holes 85, 86, and 96 is the 800-foot artesian body. Perched-water levels, artesian and non-artesian, and basal-water levels measured in test holes during drilling

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[6] Cox, D. C., 1948, Log of East Maui Irrigation Co. Kuhiwa well, Nahiku, Maui, Hawaii. Unpublished report on file with East Maui Irrigation Co., Hawaiian Sugar Planters' Association, and U.S. Geological Survey, Honolulu, Hawaii.

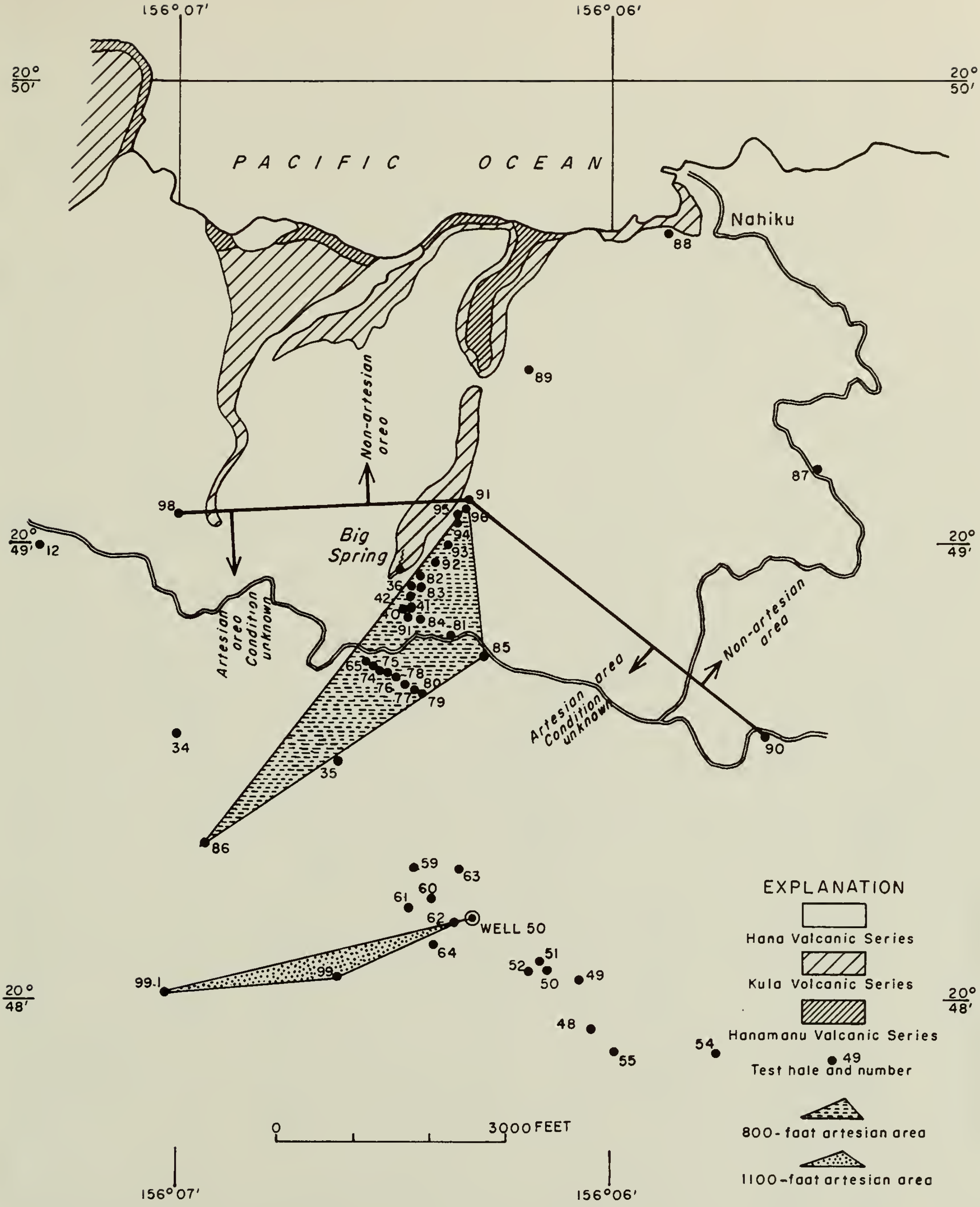

Figure 9. GEOLOGIC MAP OF NAHIKU AREA SHOWING 1,100-FOOT AND 800-FOOT ARTESIAN BODIES, NONARTESIAN AREAS, AND LOCATIONS OF TEST BORINGS

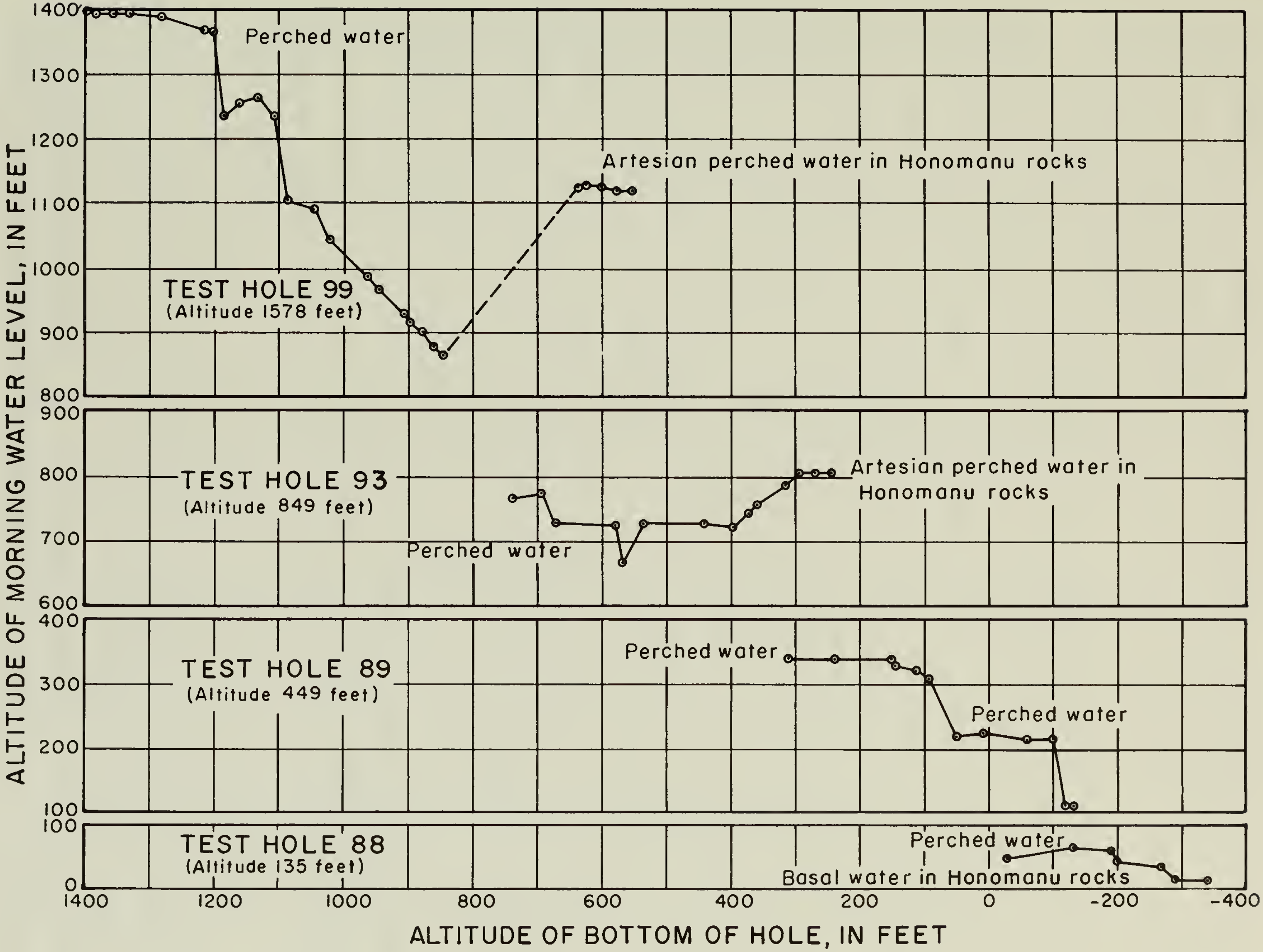

Figure 10. HYDROGRAPHS SHOWING WATER LEVELS OF VARIOUS WATER BODIES DURING DRILLING

are shown in figure 10. The altitudes of the tops and bottoms of test holes in the Nahiku area are given in table 5. The logs and water-level data are on file at East Maui Irrigation Co. and U.S. Geological Survey.

In hopes of developing water from the 1,100-foot artesian body at a suitable altitude and near their ditch system, the East Maui Irrigation Co. drilled a well 1,405 feet deep (well 50) in the Kuhiwa area. The well, 17-1/2 inches in diameter to a depth of 1,249 feet and 12-1/2 inches from 1,249 to 1,405 feet, was started in October 1947 and completed in February 1948. The well was plugged back to a depth of 1,265 feet after current-meter measurements indicated drainage from the bottom of the hole. A detailed log of the well was compiled by Cox (see footnote 6). The log includes current-meter tests, air-lift tests, bit record, drilling conditions, and a graphic, stratigraphic and hydrologic log. After exhaustive air-lift pumping tests, it was concluded that the yield of the well tapping the 1,100-foot artesian body was small. The drilling and testing of well 50, in 1948, ended the extensive ground-water investigation of the East Maui Irrigation Co. in the Nahiku area for many years to come.

Although capped, the well is available for further testing with a deep-well pump. The yield in wells of the shallow non-artesian perched-water body in the Hana lava should also be investigated.

Keanae Valley. The study by Powers (see footnote 1) covers the area in Keanae Valley below an altitude of 6,500 feet. Powers gives an estimate of average annual rainfall of 180 inches for the area. Runoff is estimated as 30 inches and evapotranspiration as 30 inches, leaving about 120 inches annually as ground-water recharge. In addition, an unknown quantity of water enters the ground as recharge by side drainage from outside the study area. Runoff from these side areas is about 60 percent of rainfall, and only the flows

Table 5. TEST-HOLE DATA, NAHIKU AREA, MAUI, HAWAII

Test hole	Altitude, feet		Test hole	Altitude, feet	
	Top	Bottom		Top	Bottom
12	1,282	354	77	1,089	809
34	1,332	1,222	78	1,107	807
35	1,293	1,070	79	1,123	823
36	942	588	80	1,103	830
40	970	553	81	984	463
41	969	791	82	924	442
42	960	774	83	944	154
48	1,500	1,309	84	977	533
49	1,484	1,288	85	1,003	12
50	1,468	1,331	86	1,494	677
51	1,453	1,318	87	465	-273
52	1,521	1,347	88	135	-340
54	1,483	1,253	89	449	-138
55	1,553	1,332	90	864	17
59	1,388	1,166	91	762	214
60	1,403	1,177	92	902	149
61	1,454	1,179	93	849	235
62	1,395	380	94	796	148
63	1,329	1,144	95	780	632
64	1,470	844	96	785	255
65	1,066	424	97	826	232
74	1,072	440	98	1,015	260
75	1,073	823	99	1,578	548
76	1,076	860	99-1[a]	1,844	713
			Well 50	1,396	- 9

[a] Also East Maui Irrigation Hole 100.

during storms reach the ocean as runoff. All the low and medium flows from these side areas enters the ground, as soon as it reaches the flows of Keanae Valley.

Ground water in Keanae Valley occurs as basal water and as perched water. Alluvium in the valley affects ground-water movement in three ways: (1) it may cause a trough or depression in the basal-water table; (2) where it is continuous, it may support bodies of perched water; and (3) if it contains interbedded lava flows, it may form the enclosing members of an artesian basin.

Powers believed that Ohia, Store, and Banana Springs discharge perched water from lava of the Ohia Basalt (a member of the Hana Volcanic Series), and that Plunkett Spring may be the result of leakage of water from the Ohia lava through permeable Honomanu rocks, or may be water perched by impermeable beds in Honomanu rocks.

Quoting Powers in his report on the availability of perched water in Keanae Valley:

"It is difficult to estimate the probable amount of water perched in the post-Pauwalu lavas (oldest member of the Hana Volcanic Series in Keanae area). The combined minimum yield of the springs in Keanae Valley is about 2,500,000 gallons a day. Some water may discharge below sea level, and a large amount may sink into the Honomanu lavas from buried plunge-pool walls. On the other hand, the minimum flow from side-wall streams which furnish most of the recharge in the lower part of the valley is less than 500,000 gallons a day, and the reservoir rock above the perching structures averages probably less than 50 feet thick. It would be surprising if the low-water yield greatly exceeded the 2,500,000 gallons a day visible in the springs. The availability of perched water can best be determined by thorough exploration of the buried stream channels by tunnels and borings."

Hana Area. Powers (see footnote 2) described the Hana area as one of great rainfall and low runoff due to the mantle of young lava. He said that ground water was abundant but was not readily available because there were no surface exposures of the possible water-bearing structures. Since then, however, the common use of deep-well pumps have readily made available ground water from deep sources.

The Hana Ranch Co. drilled an 8-inch well 280 feet deep (well 55) about one mile from shore in the Hana area. The well, drilled in January 1949, is at an altitude of about 250 feet; the water level stood about 3 feet above mean sea level. The well was tested by pumping in July 1949 at a rate of 120 gpm (gallons per minute) with no apparent drawdown. The chloride content of water from five water samples for the period 1949 to 1958 ranged from 35 to 75 mg/l (milligrams per liter). The last measurement, 41 mg/l, was made in June 1958.

Although the well is located in a rift zone, the ground water tapped is not dike-impounded water. This is likely because dike-free, permeable Hana rocks extend to some depths below sea level near the well.

Kipahulu Area. Two 4-inch diameter wells tapping the Hana Volcanic Series have been recently drilled in Kipahulu Valley about a half mile outside the southeast boundary of the study area. The wells, owned by Mr. Samuel Pryor, are at altitudes of about 50 and 175 feet and are located about 200 and 1,000 feet from the shore, respectively. Both wells were reportedly drilled to slightly below sea level, and the low water levels reported in them indicated that both wells tapped basal water. The chloride content of the water pumped from the well at altitude 175 feet was 68 mg/l on May 20, 1969. The water previously pumped from the other well was reported to be brackish.

It is likely that a basal-water body is well developed in the lower end of Kipahulu Valley where permeable Hana rocks crop out and also extend below sea level to some depth.

Other Areas. Powers (see footnote 2), in his study, discusses the following areas. Quoting from the summary of his study:

"The Puohokamoa section includes well-drained, dissected areas which yield large surface runoff and contain perched ground water occurring in small quantities in many widely scattered structures. The areas on both sides of Keanae Valley are included in this section.

"The Kailua section is a wet area in which a well developed drainage system is buried by a thin mantle of younger lava. At low altitudes most of the perched ground water has been developed by the present stream canyons, but at high altitudes the ground water is only partly tapped by surface streams. The water at high altitudes is easily accessible because the containing structures are not deeply buried."

Quality

There has been no systematic survey of water quality in the area. Water from sources now being used are generally of excellent chemical quality. Sea water probably contaminates near-shore basal-water bodies in permeable Hana rocks in the Hana and Kipahulu areas. Chemical analyses of water are given in table 6.

Table 6. CHEMICAL ANALYSES OF SELECTED WATER SOURCES IN NORTHEAST MAUI

(Constituents in miligals per liter. Analytical data by Hawaii State Department of Health, except as noted)

Source	Date	Silica ($Si0_2$)	Alumina (Al_20_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium + potassium (Na + K)	Bicarbonate ($HCO3$)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$	pH
Maui County Streamwater Supplies																
Wailua Stream	Mar. 1955	3.2	2.7		7.8	1.7	2.3		7.1	8.0	0.2	0.1	64	26.8	14	6.6
Wailuanui Stream	Mar. 1955	0.8	0.7		3.4	1.8	1.7		11.5	6.0	0.1	0.1	40	10.4	10	7.0
Waikamoi Dam	Dec. 1953	1.2	4.5	0.3	3.0	1.2	2.8		7.6	3.0	0.2	0.1	54	12.6	10	6.5
Composite sample of West and East Waikamoi; West, East, and Middle Puohokamoa; Haipuena; and Honomanu Streams	June 1963	3.6	2.5		1.0	1.9	7.4		5.4	5.0		0.1	40	10.4	11	5.8
Banana Spring	May 1969	43			8.0	6.6		86		5.0			154	47	71	7.2
Big Spring	Nov. 1948			0.2	16.2	15.7			10.6	6.7			166			6.9
Plunkett Spring	May 1969	28			6.8	5.1		57		7.0			118	38	47	7.1
Well 55	Mar. 1955	8.0	4.7		31.5	11.8	33.7		19.2	58.0	0.2	0.1	270	128	83	7.2

NEED FOR FURTHER INVESTIGATIONS

Additional streamflow information is needed to determine the quantity and distribution of streamflow at different altitudes below the ditch system. This information will complement available data at ditch level and give a better appraisal of total streamflow in the area between Honopou and Makapipi Streams.

Additional streamflow information is also needed in the area between Waihoi and Kipahulu Valleys where streams are also perennial at low altitudes. Information is needed at altitudes sufficiently high where the streams might be sources of water for the adjacent areas where streamflow is deficient.

Ground-water information outside the Nahiku area is sparse. Large diameter test holes in Keanae Valley, the Hana area, and the Kipahulu area would do much to provide information about the occurrence of ground water and the hydrologic properties of the rocks tapped.

Test holes tapping lava flows of the Honomanu Volcanic Series in Keanae Valley would provide valuable information not known about this aquifer. The upper part of this aquifer, which crops out in Keanae Valley, contains artesian perched water in the Nahiku area. Deep test holes in Keanae Valley would tap sections well below the upper transitional lavas.

Holes tapping rocks of the Hana Volcanic Series below sea level, in the Hana and Kipahulu areas, would indicate the presence or absence of basal water. If the holes are large in diameter and can be pumped, information regarding the yield and quality of basal water can be obtained.

Available holes in the Nahiku area should be pumped wherever possible to determine the yield from ground-water bodies in rocks of the Hana, Kula, and Honomanu Volcanic Series.

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